2nd U.S. – China CO_2 Emissions Control Science & Technology Symposium

Carbon Capture and Storage
Verifying Storage Capacity Assessment and MMV Issues

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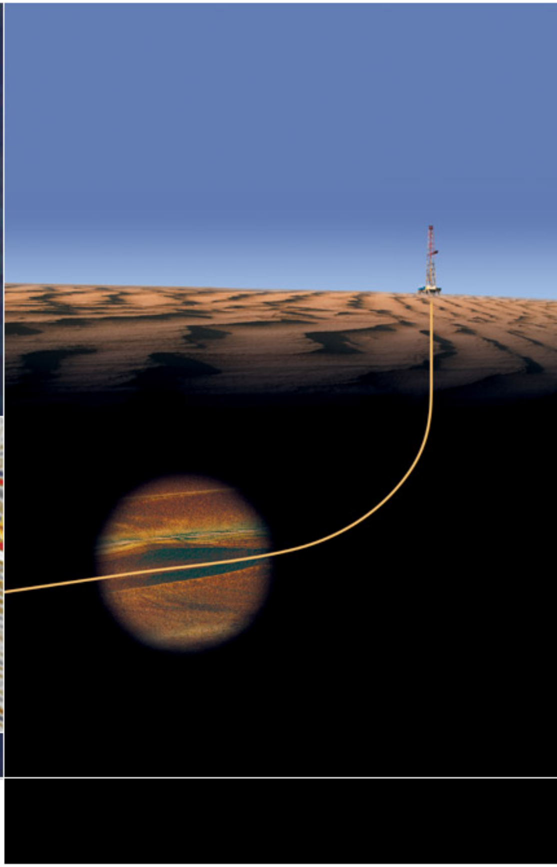
Hangzhou – May 29, 2008



Schlumberger Carbon Services Middle East and Asia

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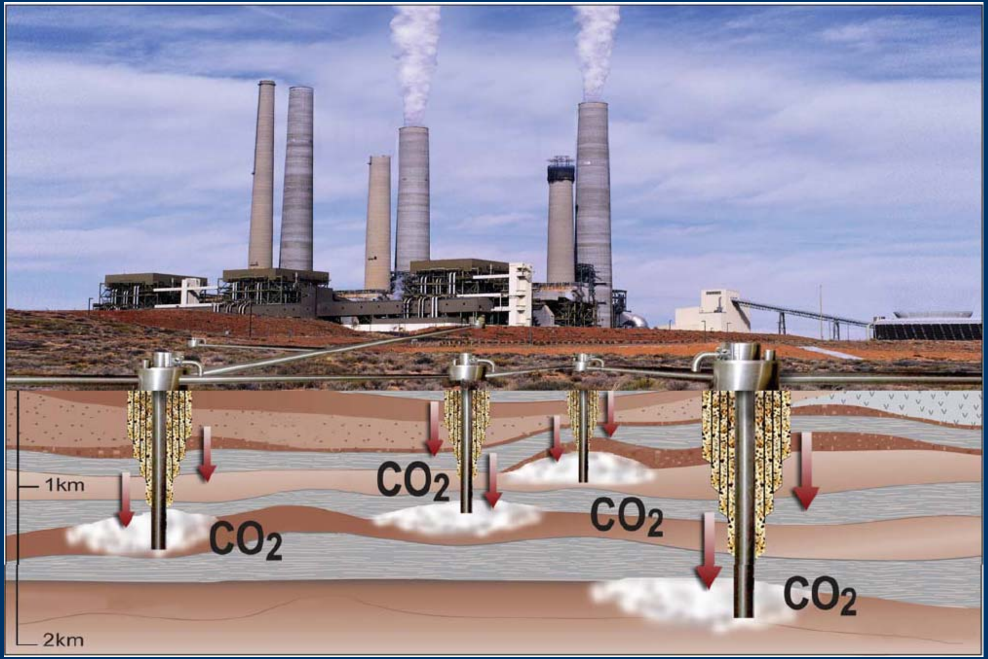
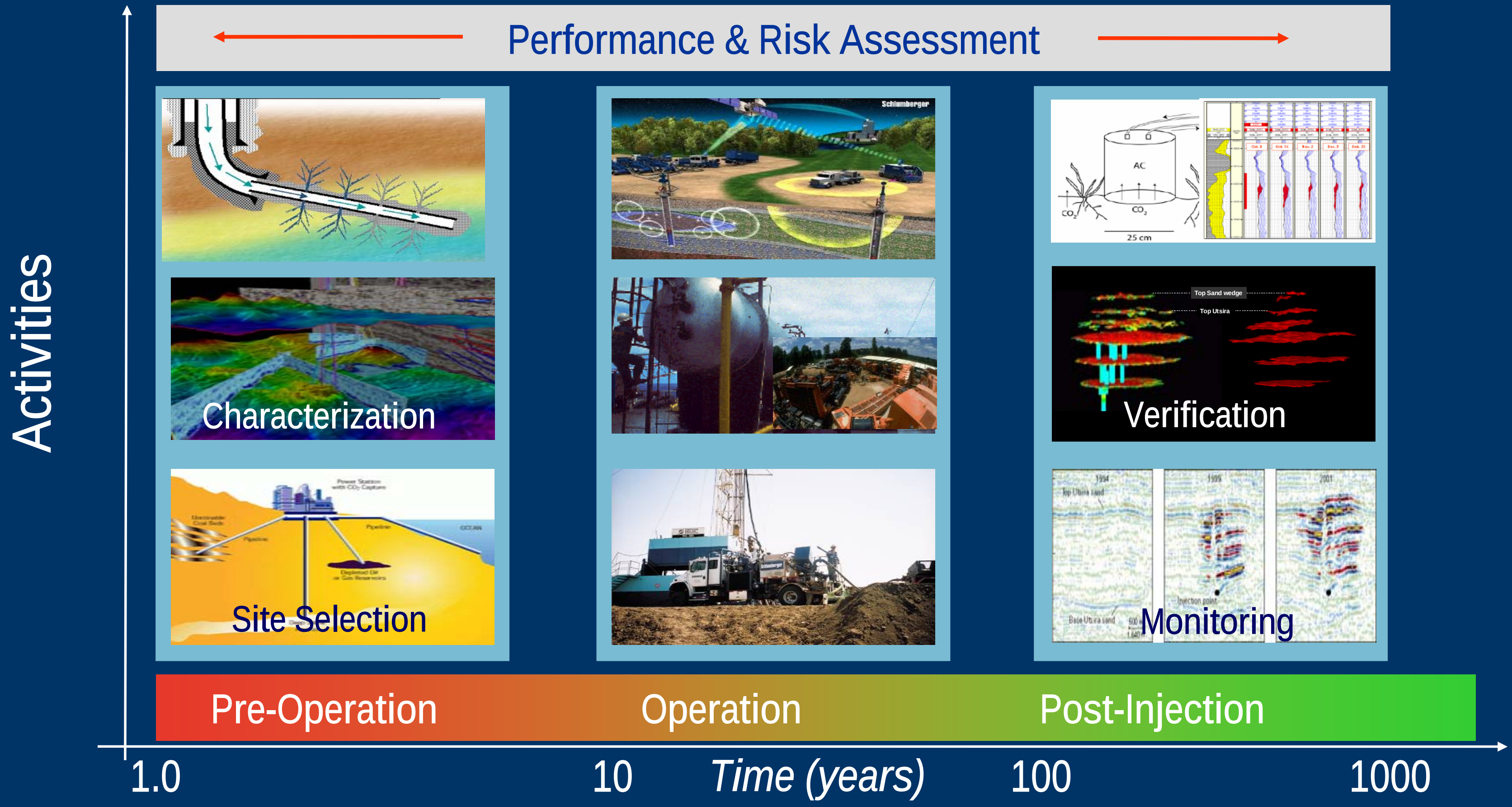
Overview

- Introduction
- Monitoring goals
- MMV technology options
- Early case studies
- Summary



CO_2 Storage Project



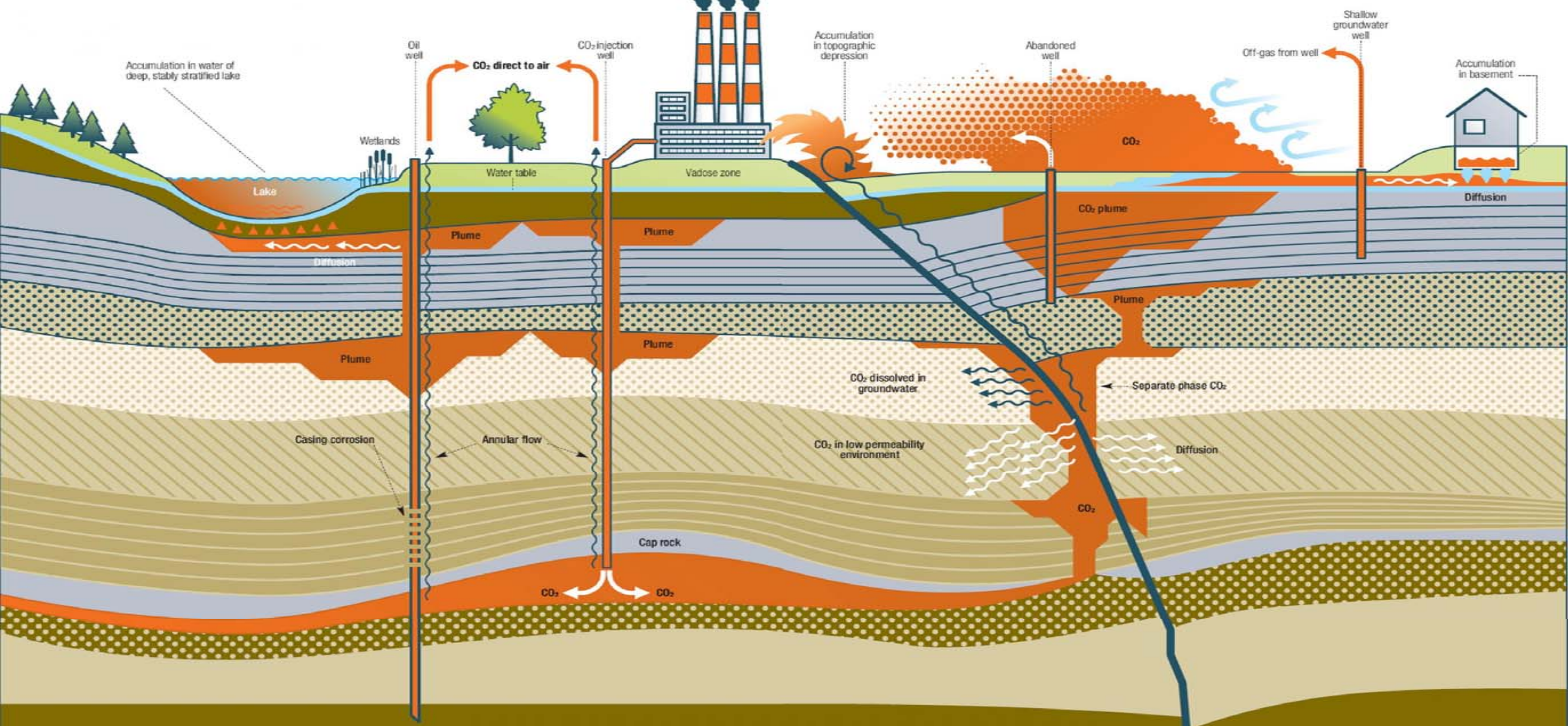
Why Monitoring?

- Health and safety reasons
- Mass balance verification
- To improve reservoir understanding
- CO_2 sequestration technology development

Cameroon Lake Nyos – August 21st 1986

Photo by Jack Lockwood, U.S. Geological Survey.

CO_2 Leakage Pathways



Source: Dr. Sally Benson

Monitoring Framework

Large Scale CO_2 Injection

Basic Fluid Effects
Fluid movement
Pore pressure

Geochemical Processes
Reactive Fluid Transport
Frame dissolution
Precipitation
Surface alteration

Geobiological Activity
Unusual populations
Couples to chemistry

Macroscopic Observations

Monitoring Techniques

- Geophysical
  - Active
    - Seismic
      - Surface
      - VSP
      - Crosswell
    - EM
    - Well Logging
  - Passive
    - Induced Seismicity
    - Gravity
    - Surface Deformation
      - GPS
      - Tilt
      - INSAR
- Hydrogeologic
  - Tracers
- Geochemical
  - Soil Gas
  - Isotope Studies
  - Water Chemistry
- Biological
  - Microbial Diversity

4D Seismic Method

Observation		Goal		Repeatable acquisition & processing		Environment
Relative change in seismic response	=	Map relative change in reservoir reflectivity to changes in S_g, P, T,GWR	+	Relative change in seismic survey parameters	+	Non-Repeatable Noise
		Rock properties		"4D Ready" Survey Design		Equipment

Three Scales for Time Lapsed Seismic Imaging

Increasing
Spatial Resolution

4D Surface Seismic
Resolution ~25 m
Coverage 10's of km
Large scale movement

4D VSP
Resolution ~ 5 m
Coverage ~ km
Near-well movement

4D Crosswell
Resolution ~1 m
Coverage ~ 100 m
Fine scale process

Increasing
Spatial Extent

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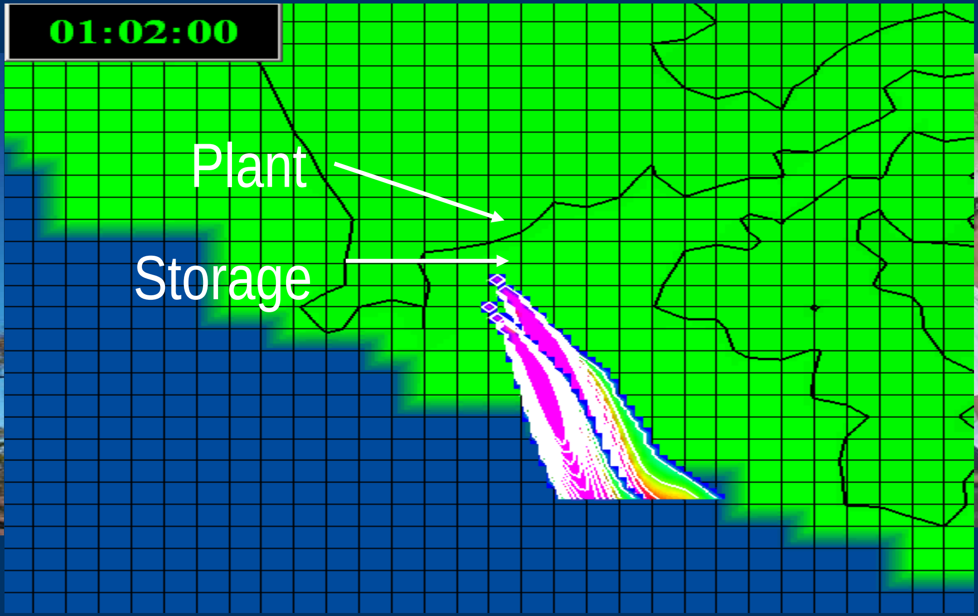
Well Oriented CO_2 Monitoring Techniques

	Measurement Type	CO_2 Injection Well	Monitoring Well
Permanent	Temperature	✓	✓
	Pressure	✓	✓
	Geophone – Passive Seismic	✓	✓
	DTS	✓	✓
Time Lapsed	3D VSP	✓	✓
	Borehole Seismic - Borehole Gravity	✓	✓
	Injection Flow Profile – DHFM, PLT	✓	✓
	X-Well Tomography (Seismic / EM / ER)	✓	✓
	MDT - CHDT – CHFR – AIT – RST – IBC - Sonic Scanner	✓	✓

Atmospheric Monitoring

Monitor CO_2 in the atmosphere and define the sources

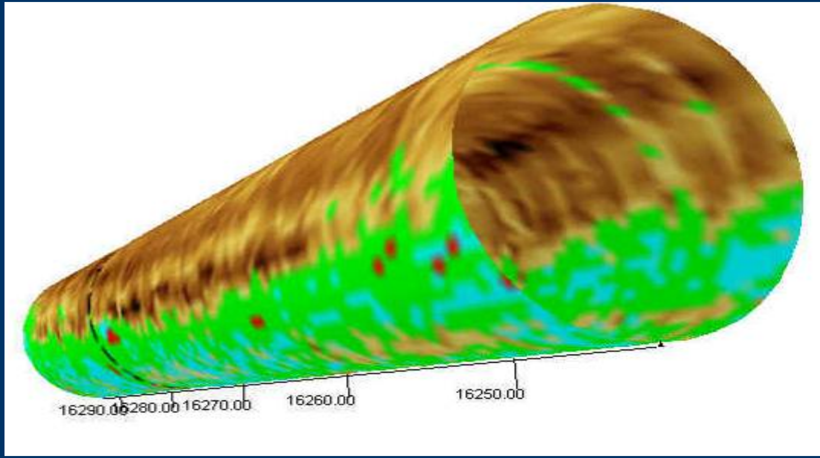
Flux Tower

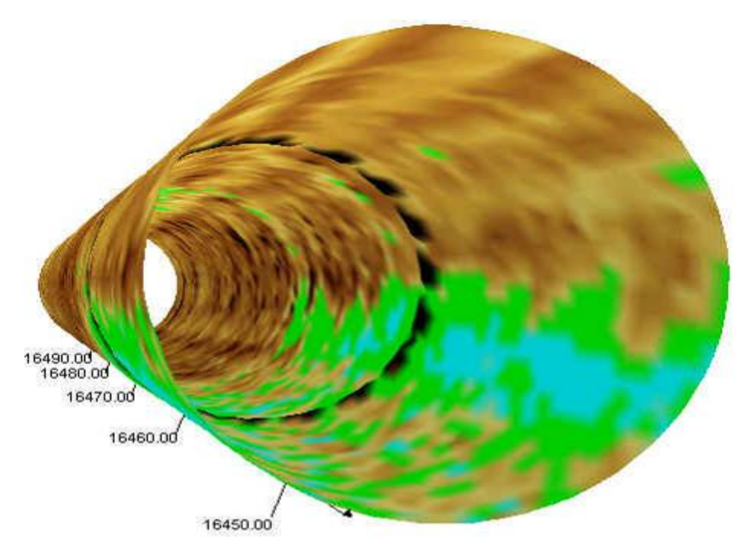


Lo-Flo *(CSRIO)*

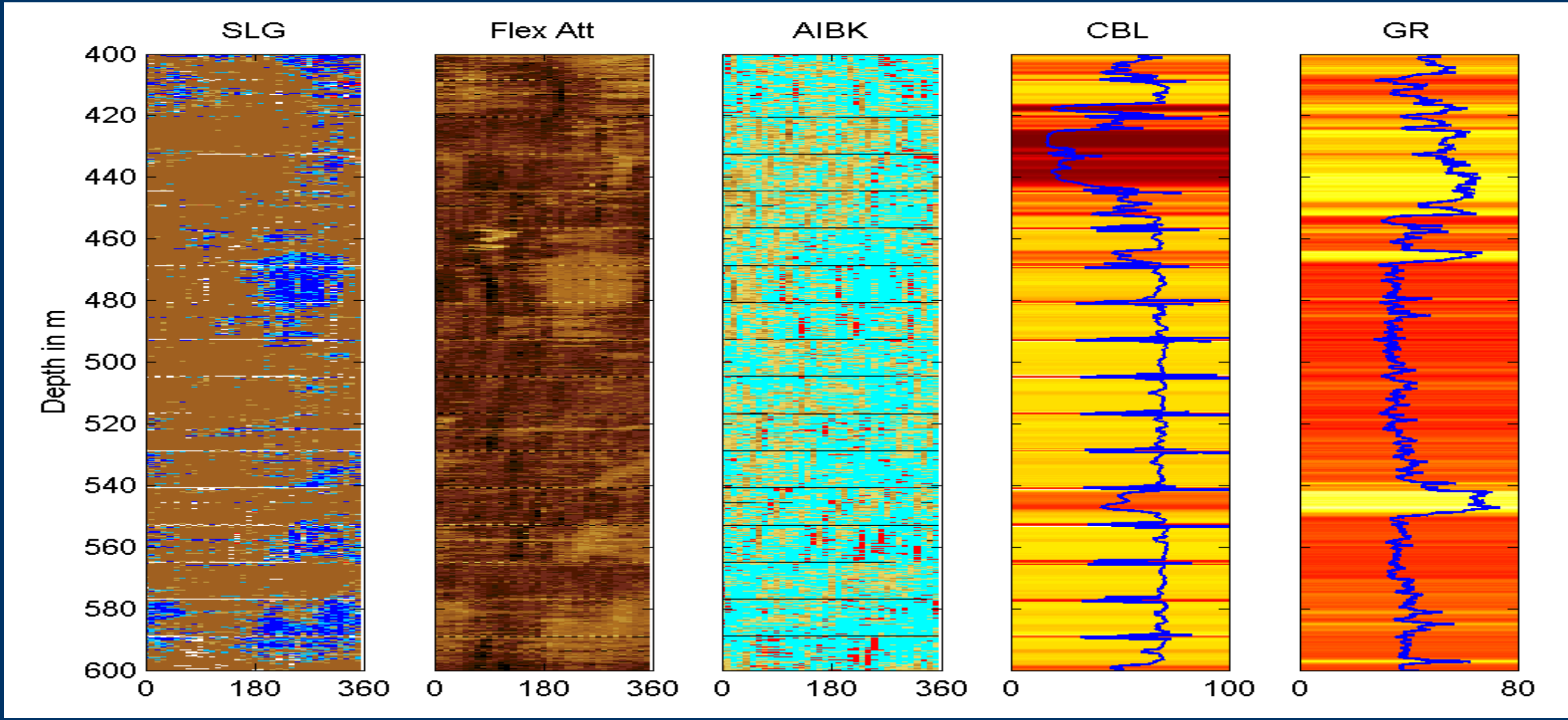
Casing Corrosion

- Image of inside or outside casing radius
- 3D Viewer

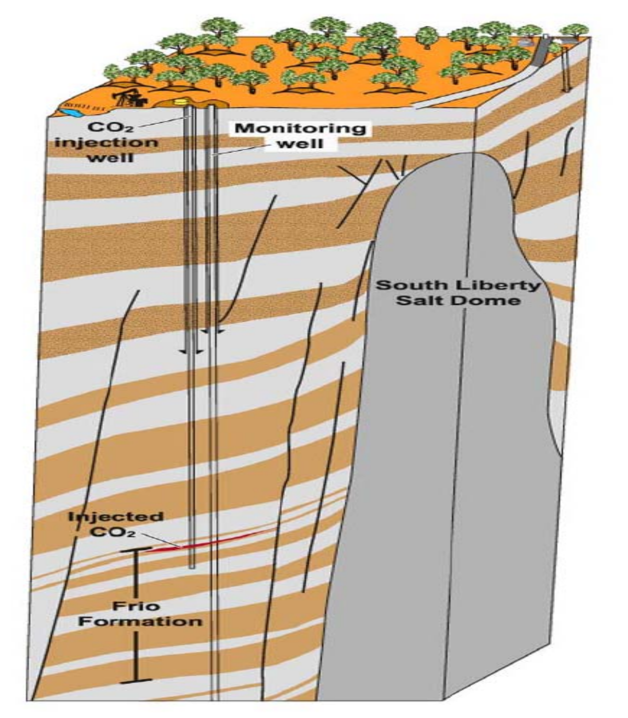




Channeled section in LiteCRETE cement

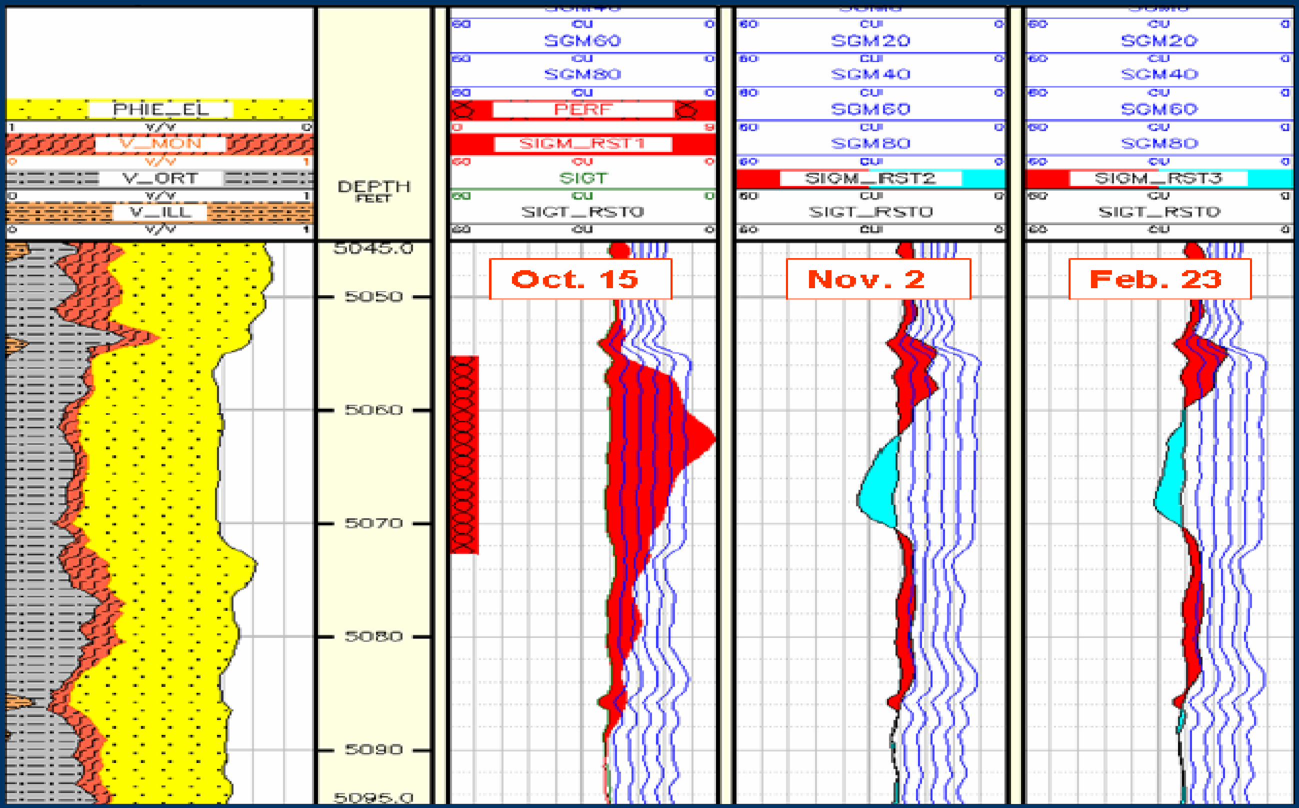


CO_2 Monitoring Using RST – Frio Experiment



- CO_2 Injection
  - started on Oct 4th 2004, stopped on Oct 14th
- 1,600 t/CO_2 injected
- Target: Frio formation (~5000 ft deep)
- Sandstone
- High Salinity: 93,000 ppm
- High Porosity: 32-35 p.u.
- High Permeability: 2.5 Darcy (air)
- Injector-Monitoring well spacing: 100ft

Monitoring Using RST – Σ Measurement



RST logging in FRIO

CO_2 injection well

Sakurai et al. , SPWLA 46th – June 26-29th - 2005

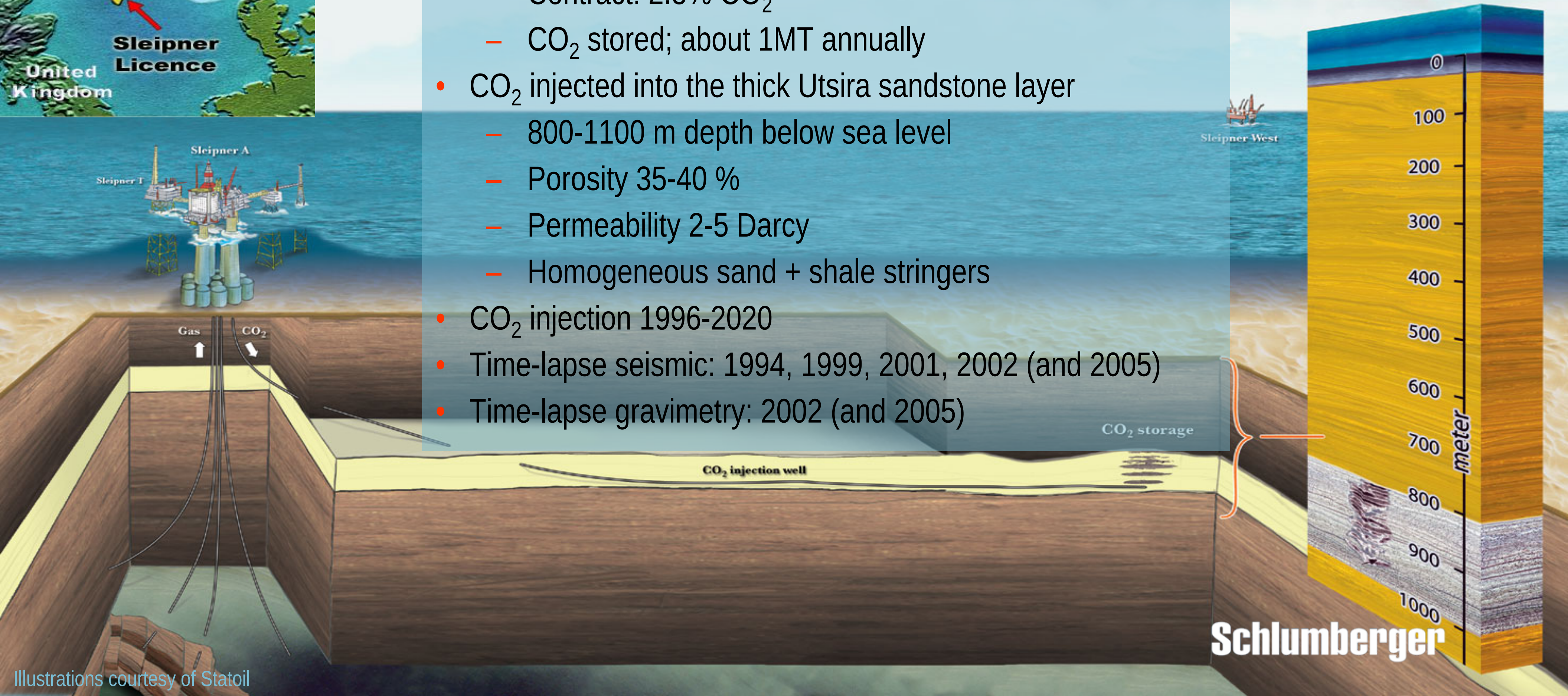
Microseismics

Main applications:

- Injection control
- Avoid fracturing cap rock
- Control CO_2 displacement
- Fault Re-activation

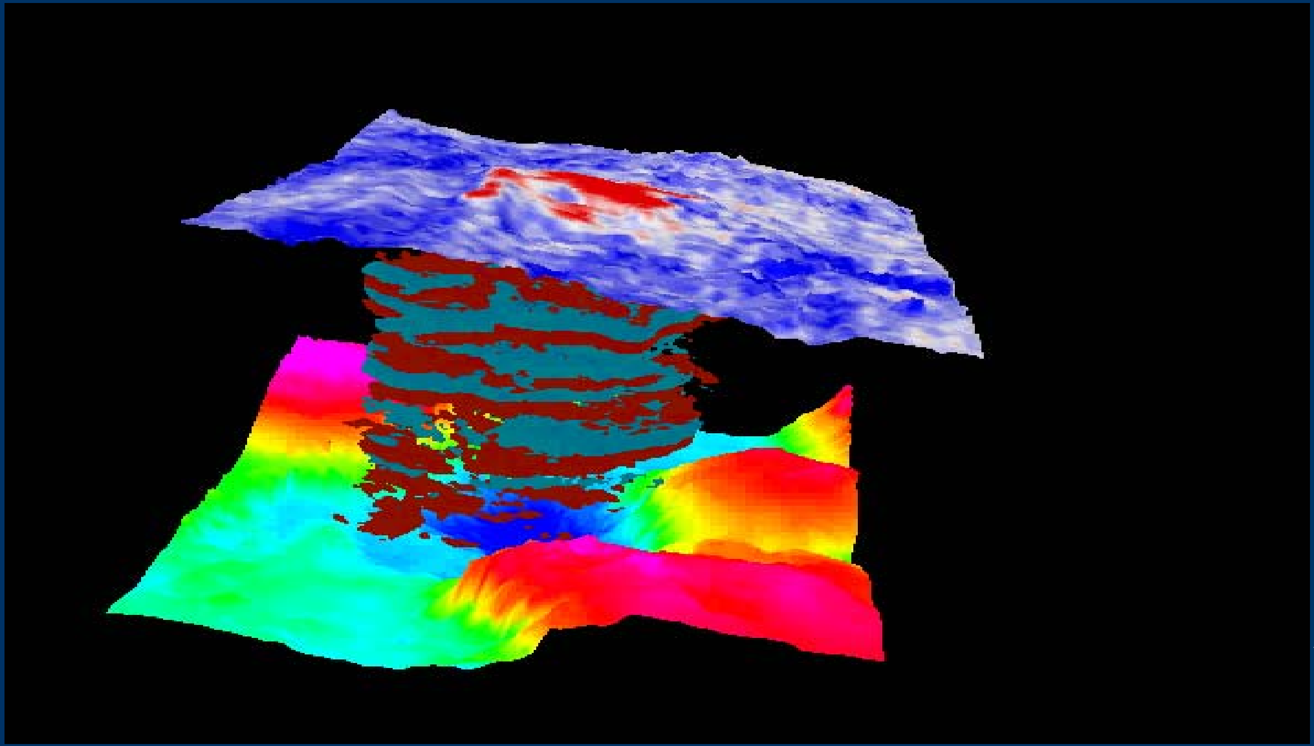
Case Study: Sleipner Project

- Sleipner natural gas contains ~9% CO_2
  - Contract: 2.5% CO_2
  - CO_2 stored; about 1MT annually
- CO_2 injected into the thick Utsira sandstone layer
  - 800-1100 m depth below sea level
  - Porosity 35-40 %
  - Permeability 2-5 Darcy
  - Homogeneous sand + shale stringers
- CO_2 injection 1996-2020
- Time-lapse seismic: 1994, 1999, 2001, 2002 (and 2005)
- Time-lapse gravimetry: 2002 (and 2005)



Illustrations courtesy of Statoil

Sleipner Seismic Reservoir Imaging



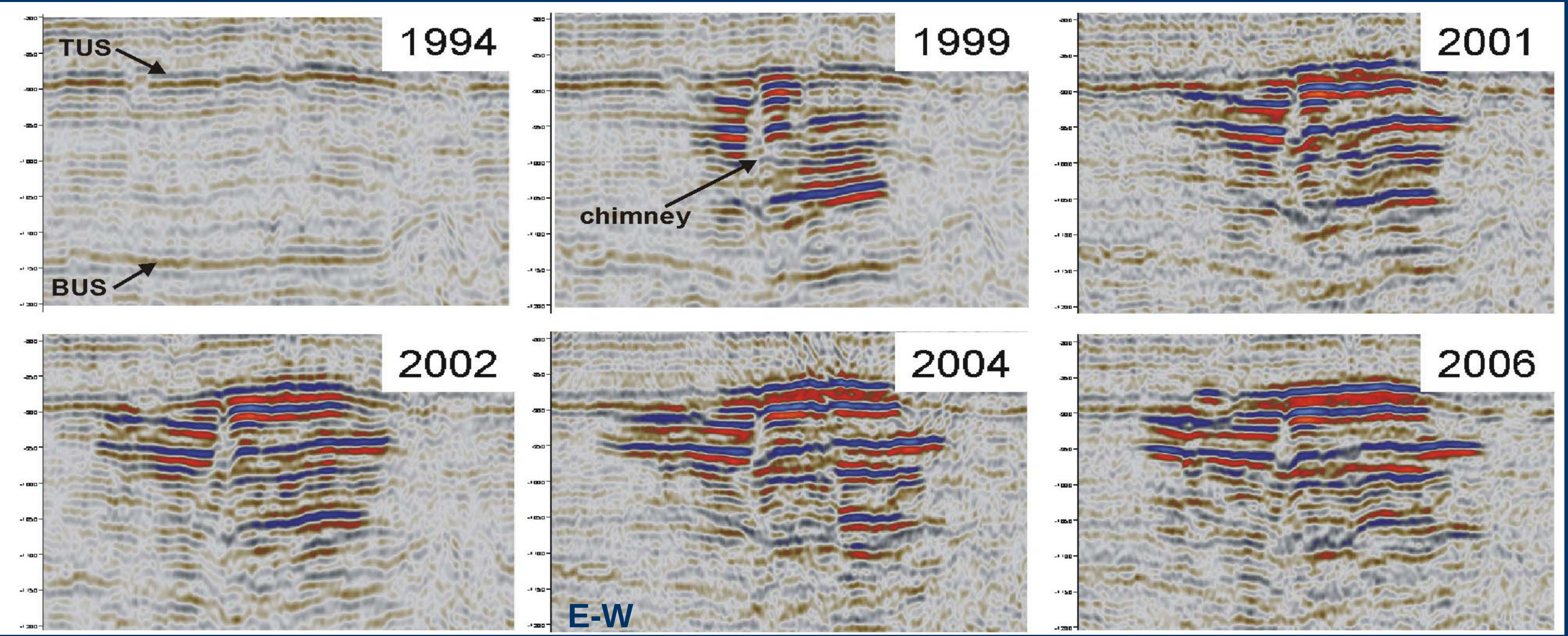
Top reservoir

Base reservoir

SOURCE: BGS- STATOIL

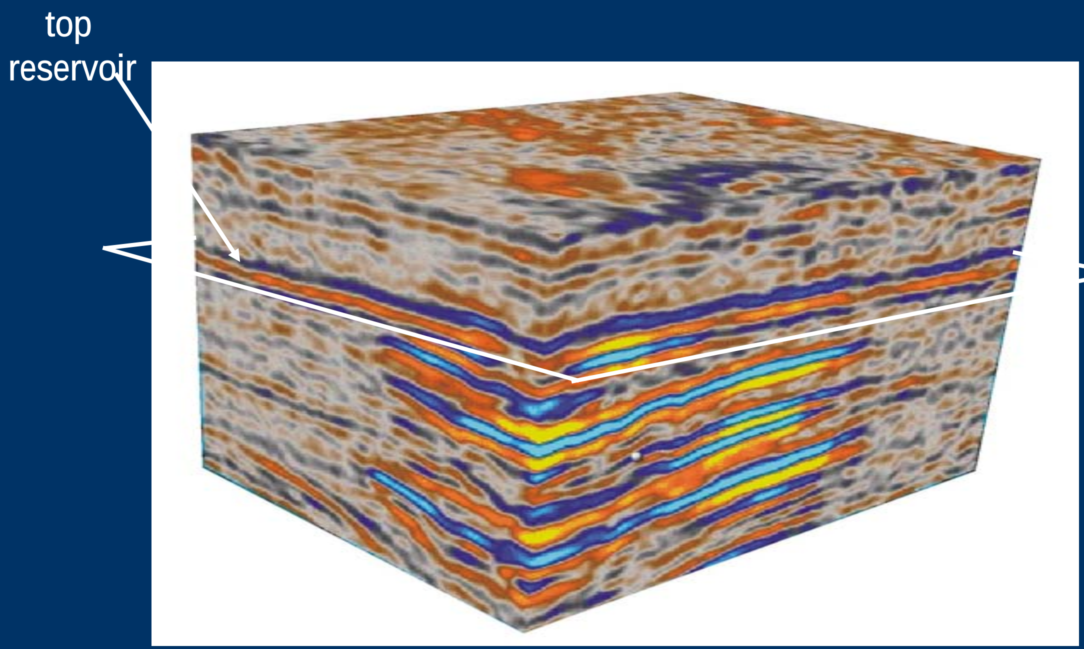
3D image of CO_2 plume in 2001

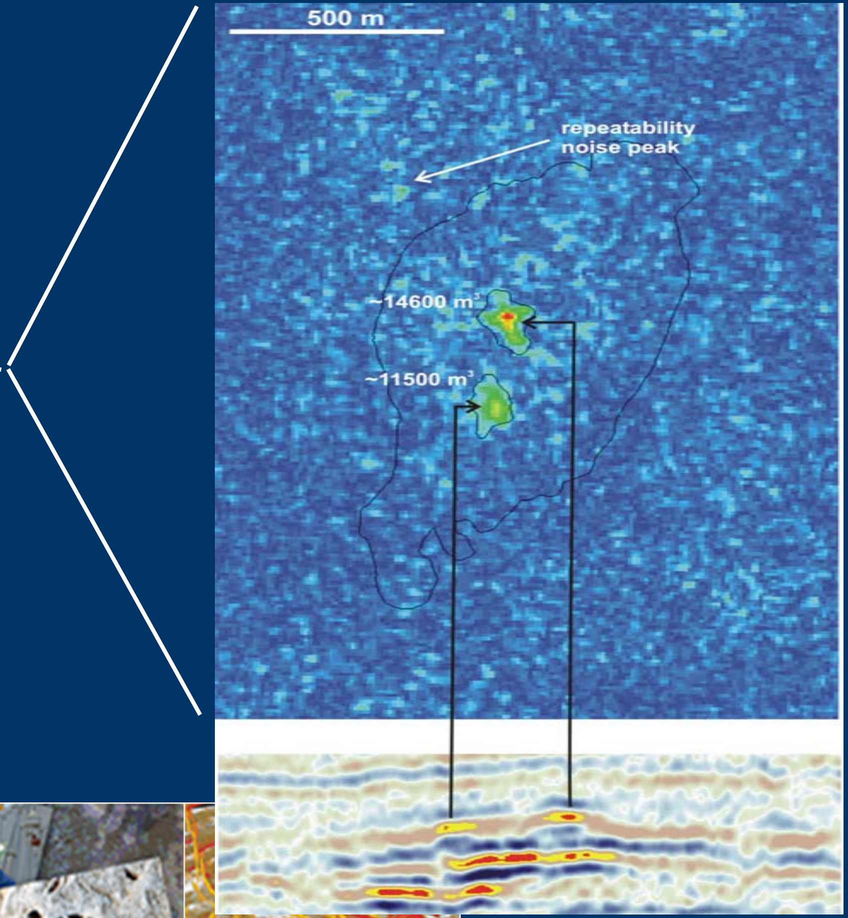
Sleipner Time Lapsed Seismic Monitoring Results



SOURCE: BGS- STATOIL

Sleipner Seismic Monitoring Quantitative Results





Detection limit for Sleipner data: ~ 4000 m^3 (<1600 tonnes at 800 m)

SOURCE: BGS- STATOIL

Monitoring Technology Options

Objective	Criticality	Surf/ VSP Seismic	Passive Seismic	Water Wells	Atmos	Soil Gas	U tube	RST	SFRT	Integrity Logs
Breakthrough detection										
Plume shape										
Plume travel path										
Plume travel speed										
Containment										
CO_2 area of accumulation										
Public Acceptance										

Schlumberger Activities in CO_2 Storage

USA and Canada

Weyburn EOR Canada
DOE Regional Partnerships
Frio Texas
Battelle Ohio-W. Virginia
Sheep Mountain Colorado
Multiple CO_2 EOR studies, Permian
Approx 70 CO_2 EOR Installations

Europe, North Africa & Russia

All France
Sleipner Norway
Snohvit Norway
In-Salah Algeria
Ketzin Germany
Karniow Poland
Various CO2 EOR studies
CO2ReMoVe
Cosmos 1+2
MoveCBM
COACH
NZEC
ANR monitoring project

Middle East & Asia

Multiple CO_2 EOR feasibility studies
Associated CO_2 prod re-injection studies
MoveCBM China

Australia

Gorgon Barrow Island
Otway Basin CO2CRC
Callide Queensland

Conclusions

- Reservoir integrity issues:
  - *Fault activation, cap rock integrity, dissolution, precipitation*
- Technologies exist to address;
  - *Integrity assessment and continuous monitoring*
- More high volume demonstration projects needed
  - *Spatial coverage and frequency of the measurement*
  - *Policy for liability*
  - *Fit for purpose monitoring scheme*
- Collaboration with all players is a must for success

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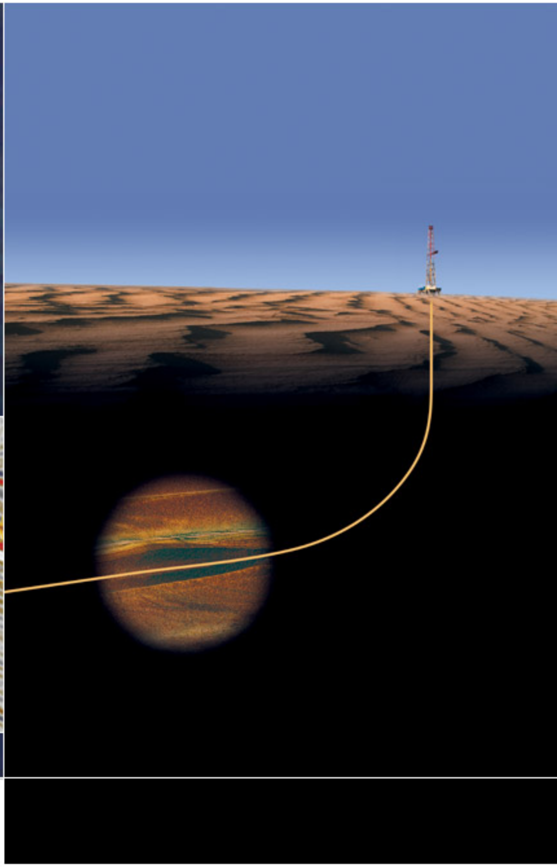
Thank you



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Monitoring and Verification Goals

Assurance Monitoring (no leakage)

- Soil and atmospheric measurements to confirm non leakage/seepage of injected CO_2.
- Hydrogeological monitoring to ensure no leakage of CO_2 into the overlying aquifers

Storage Integrity Monitoring (predicted behavior)

- Validate migration paths - geophysics
- Validate migration times - geochemistry
- Validate likely shape - reservoir properties
- Validate geomechanical integrity - coupled models

Monitoring and Verification Considerations

Reservoir

- Seal robust and sand contiguous
- Reservoir bounded by sealing faults
- Residual gas and water
- Simulation models available to predict plume movement

QRA

- Risk quotient consistent with being able to retain 99% of injected CO_2 for 1000 years in primary reservoir
- Key risk elements: Leakage through faults, Regional over pressurisation and earthquake induced fractures

M&V and Baseline Considerations

- Image on both sides of the bounding fault
- Image regionally and locally (well based) overlying reservoirs
- Consideration for regional faults in defining soil gas and water sampling grid
- Downhole pressure monitoring to control injection pressures